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Dry Bulk Time Charter Rates Joint Return Distribution Modeling: Copula-Approach

Andreas Merikas[a] , Anna Merika[b] , Henry Penikas[c] *

[a]Professor of Finance; University of Piraeus; Piraeus, LA; Greece
[b]*Professor, American College of Greece (ACG); Gravias 6, Aghia Paraskevi; Athenes, 153-42; Greece*
[c]*Senior Research Fellow of the International Laboratory of Decision Choice and Analysis; National Research University Higher School of Economics. International Laboratory of Decision Choice and Analysis; Moscow, Russia*

Abstract

The paper is the first to the knowledge of the authors to apply copula models to reconstructing joint distribution of time charter rates for dry bulk ship. Based on the Clarksons dataset for the last 20 years it is claimed that Gumbel copula is enough to perform the mentioned objective. To arrive at the conclusion the homogenous dataset in terms of copula structural shifts' absence is used; a system of criteria for copula selection based on goodness-of-forecast criteria is implemented. The evidence suggests dry bulk time charter rates weekly returns exhibit symmetric distribution.
As an auxiliary output stands for the result of copula fit accounting for time dynamics and not. For the purpose of conservative analysis (i.e. risk-management) approach disregarding time-dynamics should be preferred as yielding the least number of value-at-risk breaches. From the risk budgeting perspective non-conservative approach (accounting for time dynamics) might be preferred as reflecting the rapidly changing value-at-risk.

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Keywords: copula; time charter rates; shipping; structural shift; goodness-of-forecast.

1.1. Introduction

The **objective** of the current research is to model the joint distribution of dry bulk time charter rates. It is of primarily importance for the shipowners to plan their capital expenditures and credit facilities given the

* Corresponding author. Tel.: +7-495-772-95-90, ext. 4330.
E-mail address: gpenikas@hse.ru.

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envisaged critical levels of rates that might make it viable to expand or to continue doing business.

The paper is organized as follows. Section 2 presents the relevant literature review. Papers dealing both with shipping and rates forecasting are discussed. Section 3 is devoted to description of the unique dataset on time charter rates dynamics that formed the basis for the current research. Section 4 described the methodology of the research, special attention is put on the role of copulas in joint distribution modeling. Approach to structural shift identification is briefly discussed with reference to the paper of Brodsky et al. [2] and with extension to the use of Cramer-von Mises statistics, not being limited to Kolmogorov-Smirnov ones (both actually deliver common results as the research proves). Section 5 comports the key research findings, including the justification for Gaussian copula choice based on goodness-of-forecast criteria. Section 6 concludes the paper.

1.2. Literature review

Shipping has recently become one of the target research areas. From one side, being linked to oil prices, it well serves the barometer for the level of the world economic activity. From another, it vividly depicts the trade comparative advantages in-between countries and their evolution with the time.

All the shipping industry can be broadly broken down into two segments: passanger and cargo. The latter is the subject of our interest. Particularly, only one of three cargo shipping types are of focus to current research. Brief summary of papers dealing with various data is presented in table 2. Out of dry bulk, container and tanker it is the former to be researched.

Table 1. Copula Structural Break Dates Identified.

Paper Reference	Container	Dry Bulk	Tanker
Angelidis et al. [1]		x	x
Goulielmos et al. [5]		x	
Mehrara et al. [8]			x
Randers et al. [11]			x
Sodal et al. [13]		x	x
Veenstra et al. [14]		x	
UNCTAD [10]	x	x	x
Groder [6]	x	x	x
Velonias [15]			x
Weimar-Rasmussen [16]	x		
Wilken [17]		x	

Previous papers applied different methods and models to reconstruct distribution of rates in shipping. None of them dealt with joint distribution decomposition with the use of copulas.

Previous research was based on a wide variety of data windows and data frequencies. The longest window was considered by Randers et al. [11] that took about 50 years of data, but predominantly dealt with yearly data. Daily data was looked at by Angelidis et al. [1] and Groder [6]. But their research covered seven and five years only, respectively.

1.3. Data Description

Current research is based on the unique dataset provided by Clarksons. It includes weekly time charter rates for all ship sizes and maturities for the last 20 years starting January 1992 and ending January 2012

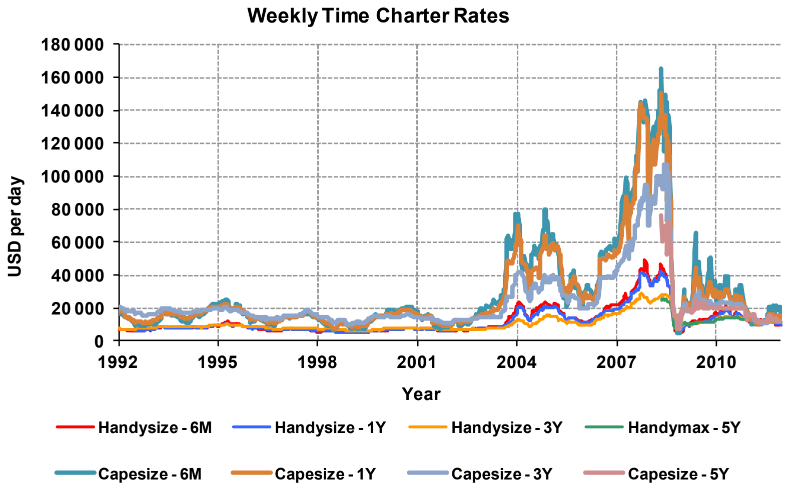


Fig. 1. Dry Bulk Time Charter Rates Dynamics.

The time charter rate dynamics for selected maturities and ship sizes is presented at the Figure 1 above. Corresponding to the world economic boom period the interval of 2003 – 2008 was characterized by unprecedentedly high rates. Even though it was the moment of China actively increasing the global offer of ship, it was unable to absorb the rapidly rising demand for ship.

To mention time charter rates are differentiated by ship sized measured in k dwt and by maturities. Standard ship sizes included Handysize (16 and 30 k dwt), Handymax (45 and 52 k dwt), Panamax (65 and 75 k dwt) and Capesize (127.5, 150 and 170 k dwt). We excluded from our dataset series on Handysize 16 k dwt and Capesize 127.5 k dwt as the respective contract quotes terminated in 2003 and 2008.

The range of maturities comports 6 months (6M), 1 and 3 years (1Y, 3Y). After the start of 2008 world financial turmoil new contracts of 5 year length were introduced as might be supposed for the purpose to fix low rates for those who rent and to guarantee at least some revenue for those who lend. Not to shrink our dataset by excluding observations before June 2008 when 5-year contracts were presented, it was chosen to exclude 5 year contract rents and to focus on 6M, 1Y, 3Y ones, i.e. on a trivariate joint distribution.

Data analysis from the first glance suggests that correlations between rates as well as volatility changes with a time. As it might be expected volatility almost doubles and correlation increases by some 10-20 percentage points in crisis times (when rates tend to fall) compared to prosperity period.

Finally we decided to focus our analysis on the data range 2002 to 2012 to have records for all 7 ship sizes (namely 30, 45, 52, 65, 75, 150, 170 k dwt) and for all three maturities (6M, 1Y, 3Y), i.e. 523 observations.

To finalize our explanatory data analysis we may conclude that neither constant marginals (with constant disturbance term), nor Gaussian joint distribution might suit us as correlation is neverever also constant. That implies the need to find a model that might decompose the task of marginals and dependence modeling. Copulas discussed below serve properly for the mentioned task.

1.4. Methodology

To model dry bulk time charter rates joint return distribution we partitioned the task in two. First we fitted marginals, then investigated dataset homogeneity in terms of copula structural break absence, afterwards tested for joint variates independence and finally searched for appropriate copula. We justified the choice of copula by a set of criteria using out-of-sample forecasting interval.

Fitting Marginals

To fit the marginals we used two approaches. First was ARMA(1,1)-GARCH(1,1). Second approach was to escape from time dynamics and to deal solely with historical empirical marginals.

Copula Definition

To briefly remind copula C is a function that 'couples' (joins) F-marginals to arrive at the joint H distribution (see formula below).

$$\forall \mathbf{x} \in \bar{\mathbf{R}}^n: \quad H(\mathbf{x}) = C\left(F_1(x_1), F_2(x_2), \ldots, F_d(x_d)\right), \tag{1}$$

Where $\mathbf{x}$ – is a vector of our d-variates.

More extensive coverage on copula can be found in Nelsen [9].

The nice properties used by copulas come from the Sklar theorem that was presented in Sklar [12].

For the purpose of the study seven copulas were fitted: Gumbel, Clayton, Frank, Gaussian, Cauchy (Student with 1 degree of freedom), Student with 3 and 10 degrees of freedom.

Copula Structural Break Analysis

In order to deal with homogenous dataset for the purpose of future joint distribution reconstruction the dataset is tested for the presence of copula structural break. The procedure proposed in Brodsky et al. [2] is implemented. Still the algorithm is augmented by adding Cramer-von Mises statistics analysis, not being limited to only Kolmogorov-Smirnov one (please, see respective formulas below).

Test of Independence

In order to test whether our trivariate data exhibit independence we use independence test proposed in Genest et al. [4]. The idea of the test is quiet obvious, though of high use. It evaluates whether the empirical copula (equivalent of the empirical distribution function) corresponding to our data represent independence case or not, i.e. can be modeled by product copula or not.

All estimation is run in R software package.

1.5. Econometric Output

As an example below is presented the result of ARMA(1,1)-GARCH(1,1) estimation for 30 k dwt. Standard errors are given in parentheses.

$$\begin{aligned} r_t &= \underset{(0.07642)}{0.01633} + \underset{(0.10040)}{0.63195} \cdot r_{t-1} - \underset{(0.12047)}{0.41916} \cdot \xi_{t-1} + \xi_t \\ h_t &= \underset{(0.59984)}{0.75990} + \underset{(0.06463)}{0.09921} \cdot h_{t-1} + \underset{(0.03035)}{0.91023} \cdot \xi_{t-1}^2 \end{aligned} \qquad (2)$$

The shape parameter for conditional Student distribution equals 2.47782 (0.28974).

As for the example the fitted model has significant coefficients except for intercepts and first lag of variance.

After fitting ARMA(1,1)-GARCH(1,1) model to all 3*7=21 series we proceeded to testing for copula structural shift. The results of copula structural break identification are given in Table 2 (KS stands for Kolmogorov-Smirnov statistics; CM – for Cramer-von Mises).

Table 2. Copula Structural Break Dates Identified.

k dwt	**30**	**45**	**52**	**65**	**75**	**150**	**170**
KS-stat	0.0696	0.0641	0.0570	0.0703	0.0652	0.0607	0.0650
KS-obs	75	82	452	478	100	413	50
KS-date	08-Jun-90	27-Jul-90	29-Aug-97	27-Feb-98	30-Nov-90	29-Nov-96	15-Dec-89
CM-stat	3.0082	2.6158	2.0209	3.3644	1.8212	2.2242	2.0311
CM-obs	32	32	31	502	22	28	22
CM-date	11-Aug-89	11-Aug-89	04-Aug-89	14-Aug-98	02-Jun-89	14-Jul-89	02-Jun-89

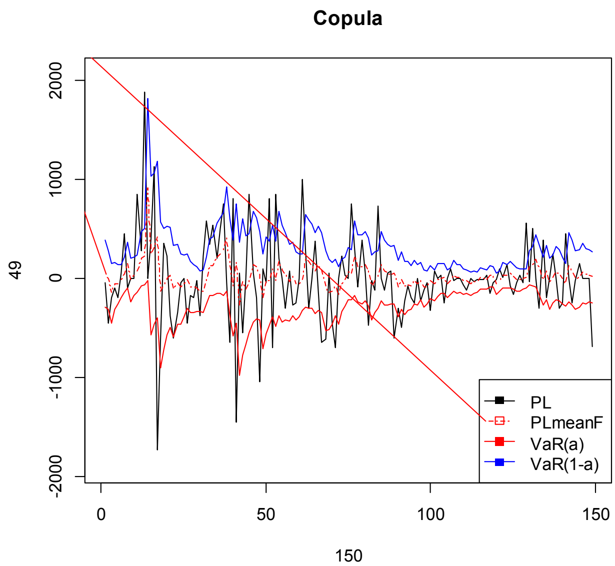
Because of the identified structural break point that is ca. 80 observations past the start of the series, the dataset was reduced by the first 80 observations (last break dates of ca. 450th observation imply deletion of most of the dataset that is inappropriate).

After having identified the structural break the test of independence was run. Pairwise dependence is quiet strong (null hypothesis for inpedendence is rejected as the height of lines exceeds the points – critical values – at the very bottom). Still for a trivariate case the situation is close to independence (as a result the best copula chosen is Gaussian as would be shown later on).

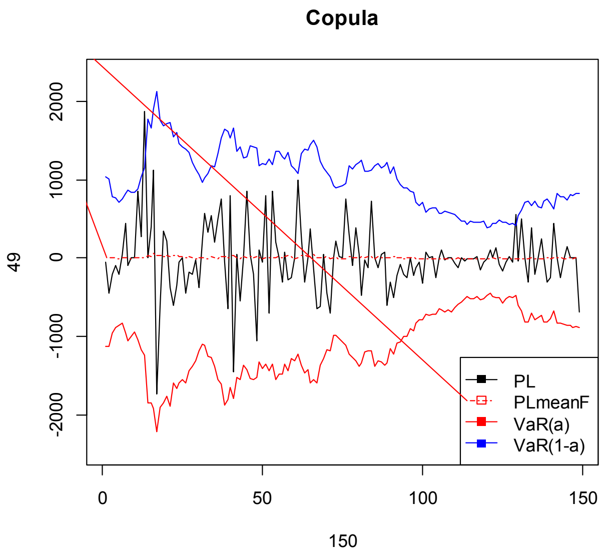
Then was the out-of-sampling forecasting of a hypothetical ship-owner profit given equal number of vessels in all three maturities he offered for rent. Thus similar to Angelidis et al. [1] Value-at-Risk (VaR) concept was applied. This enabled to use goodness-of-forecast criteria to copula choice. The criteria set included four:

- Relative number of VaR breaches compared to confidence level (5% was used by default);
- Root mean squared prediction error;
- Semi-variance as introduced by Markowitz [7];
- Maximum breach when occurred;

An interesting fact observed is presented below when comparing to approaches: time-dependent one and not-time-dependent (see Figure 2).



(a) AR-GARCH Approach



(b) No Time Dynamics Accounted For

Fig. 2. Value-at-Risk Estimate Based on Two Approaches Using Copula-Models.

As it can be seen from Figure 2, not-time-dependent approach (b) yields more conservative estimates, but resulting in mostly no breaches whereas time-dependent one (a) is more flexible, but results in number of breaches that is much higher than that of confidence level.

To come with the final choice of copula the above mentioned criteria should be considered. First we exclude copulas yielding highest number of breaches. This is definitely Cauchy one. Then we do not continue using the ones with the highest root mean squared prediction error. These happen to be Clayton and Student with 10 degrees of freedom. Finally we are arriving at the preference of Gumbel copula. Detailed comparison can be presented upon request.

1.6. Concluding remarks

The analysis of seven joint dry bulk time charter rates return distributions was done to be able use it in portfolio optimization settings. Though observing strong rise in correlation in crisis and rejecting independence on a pairwise basis fitting unique copula to a trivariate case yields us with the best outcome as the Gumbel copula. Further research implying deeper analysis of pairwise dependences including hierarchical copula models.

It was found that Kolmogorov-Smirnov and Cramer-von Mises statistics deliver comparable outcomes in terms of potential break date.

An interesting result is that using no-time-dependent approach for marginals might be preferred to risk-management purposes as it delivers VaR estimates with breach number within the confidence interval.

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